Equivalent-time sampling versus real time:
Why should you care?

Jit Lim - June 23, 2011

To follow up last week’s discussion on real-time versus equivalent-time oscilloscopes, I asked my colleague Pavel Zivny to send along his thoughts. Pavel, who’s a domain expert for high-speed oscilloscopes and serial data measurement, did more than just send along a few comments. He wrote a complete (and long) post that I’m sharing with you now. Enjoy.

Oscilloscope acquisition methods are broadly divided into RT (real time) and ET (equivalent time). While the difference in utility between the two is obvious for some measurements—say, power-up sequence—it is reasonable to ask what, if any, difference there is for serial data applications.

Let’s start with some terminology

The RTOs (real-time oscilloscopes) are the easy case; they acquire samples fast enough to reconstruct all of the signal within their bandwidth and dynamic range. This means that they have to sample at over the Nyquist; that is, their sample rate is more than 2x their BW. For example, 50 GS/s is sufficient for a 20-GHz oscilloscope. Normally they digitize with a clock that is asynchronous to the DUT. In the case of acquiring a serial data stream, every acquisition will be captured with a random phase between your serial data clock or data stream and the digitizer. The trigger is often not essential; more about this later. Besides operating with the real-time acquisition mode, many RTOs also support an equivalent-time mode. In this mode of an RTO, the digitizer is still running asynchronously of the DUT, and as many repetitive acquisitions of the signal are made, phase between the oscilloscope’s digitizer and the DUT’s clock randomly varies. What’s different is that this time the trigger timing information is essential, and is used to place the acquired points into the record, relative to the same trigger point, which in the case of a serial data acquisition would be in a fixed relationship to the DUT’s clock.

Since many acquisitions are made, the sample-to-sample spacing will be smaller than the spacing the digitizer exhibits—and the resulting apparent sample rate can easily reach TS/s. And because the phase of acquisitions is random, the mode is called random equivalent-time sampling; the sample-to-sample spacing randomly decreases as the number of acquisitions grows, but strictly speaking is not guaranteed. It remains random.

And last, the “sampling” oscilloscope: The acquisition system of a sampling oscilloscope is time-locked to the trigger. In serial data the trigger is fired on the DUT signal or clock, and the acquisition samples are taken synchronously to the trigger. For serial data acquisition, this means a controlled phase relationship to the DUT; samples are taken in a sequence from left to right, in increasing time or phase from the trigger, in a method that is properly known as sequential equivalent-time sampling. The name “sampling oscilloscope” was sufficient long ago (when other oscilloscopes were analog in both a time and vertical sense) but is hopelessly overloaded today when
all oscilloscopes take samples in time. As a result, the name “sampling oscilloscope” is an anachronism; terms such as “signal analyzer” or “communication analyzer” are a bit more up to date but not very specific, and thus a certain name confusion exists.

**Serial data and oscilloscope acquisition method**

The key point for a serial data receiver is that everything depends on the relationship between the receiver clock and data. For example, the data stream into the RX can be jittered, but if the clock recovery tracks the jitter, and the relationship between the data and clock is fixed or within a small fraction of the UI, the data can be recovered.

The measurement tool should follow this logic, and so the serial data stream is typically shown plotted in with phase relative to the serial data clock. In a real-time oscilloscope, an SW that processes the captured data stream can generate the recovered clock, and this is a great way to do it. In the case of an ET oscilloscope, a real-time captured data stream doesn’t exist, so the recovered clock has to be non-virtual; a true hardware clock recovery similar to the one in a real receiver is needed.

**Why consider equivalent-time sampling when acquiring serial data**

Very high bit rates used in serial data communication often stress the acquisition system of an RTO in terms of available sample rate. If the oscilloscope acquires only a few data samples per UI of data, the acquisition might still be within the Nyquist of the signal spectrum, but a low amount of oversampling stresses the oscilloscope’s ability to correctly interpolate the samples for a clear, fully sampled eye. A small amount of noise will exist beyond the Nyquist, disturbing the accuracy of the interpolation even if a perfect algorithm is used.

Equivalent-time sampling can limit or avoid any interpolation since the equivalent (virtual) acquisition rate is not limited by the digitizer sample rate and can be huge. This advantage has its price: As mentioned above, you need an HW clock recovery. The jitter of the captured data is burdened with the jitter floor of the clock recovery and the trigger path of the oscilloscope, and so the jitter floor of your measurement will be worse than with the real-time acquisition. On a real-time oscilloscope you might try both methods—the real-time capture and the equivalent-time capture—to compare the trade-off of the methods.

A sequential equivalent-time oscilloscope presents a slightly different trade-off: The trigger jitter has been minimized by continuous efforts of oscilloscope designers, so the jitter floor issue is not a large concern. Additionally, because the available bandwidth is typically much larger than the spectrum of the DUT’s signal, the bandwidth roll-off of the oscilloscope is not invisible in the captured response of the device. With the vertical interpolation issues removed and the jitter floor of available oscilloscopes low enough, the ET oscilloscope presents the most accurate method to characterize the serial data waveform. The trade-off is another consideration; namely, the limited usability of the equivalent-time sequential sampling oscilloscope for the less repetitive or nonrepetitive measurement tasks.

**Trigger point, trigger counterpoint**

Depending on the DUT setup, a clock from the DUT might also be available. The temptation also exists to use such a signal as the timing reference for the measurement. This approach is practical—saving on the need for clock recovery—but generates its own problems that should be understood before proceeding.
In the case of an RTO, the acquisition relative to the HW clock signal provided by the DUT or the DUT test setup can lead to a rosy view of the signal. Since the RTO is triggered instantaneously, UI errors will not accumulate, at least not right at the trigger point. In contrast, the DUT’s (receiver’s) clock recovery circuit is not following the signal’s clock errors instantly; some jitter accumulation will occur, and the result in a realistic receiver is then easily much worse than what is seen on the RTO’s oscilloscope screen. This consideration remains even with a RTO running in random equivalent-time mode.

The recommendation, then, is to either not use such a simple acquisition method, and fall back on the clock recovery circuit with parameters similar to that of the DUT, or verify the stability of the trigger signal clock in another way in an additional step of the DUT verification.

In the case of a sampling—sequential equivalent-time—oscilloscope, a certain amount of jitter accumulation might be provided unwittingly by the long trigger-to-sample time, and in fact this method can somewhat be used by the real-time oscilloscope, as well. Once again, however, a complete clock recovery (this time by necessity in HW) is a safe way to see what the receiver will see.